Broadcast Signal Lab

Considering Measurement Requirements for IBOC Radio

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IEEE BTS 2004

Topics

- Guidelines for Spectral Occupancy
  - Host Compatibility
  - Spectrum Compatibility
- Power Measurements
  - Uniform Methods
  - IBOC Topologies

First Thought

- IBOC
  - Truly “Hybrid” of analog and digital
- Measurement issues
  - A & D Signals measured differently
  - Signals close in frequency
  - Digital potential for intermodulation

First Thought

- Compliance issues
  - FCC enforcement depends on repeatable, verifiable methods
    - Measurements should employ consistent technique(s)
  - Quality of service depends on industry self regulation
    - Measurement skills vary among radio stations

Power Reference

- Case Study of FM
- FM analog carrier is the primary reference
- Digital carriers sometimes the reference
  - Suggested convention:
    - Using "dBc_{FM}" for analog FM reference
    - Using "dBc_{PM}" for IBOC Primary Main OFDM carrier power (stipulate bandwidth!)

Making the Measurement

- Spectrum analyzer
  - Convenient
  - Familiar

    but…
  - Room for error
    - There are <u>many</u> setting options– results vary.
    - Must be able to interpret the measurements.

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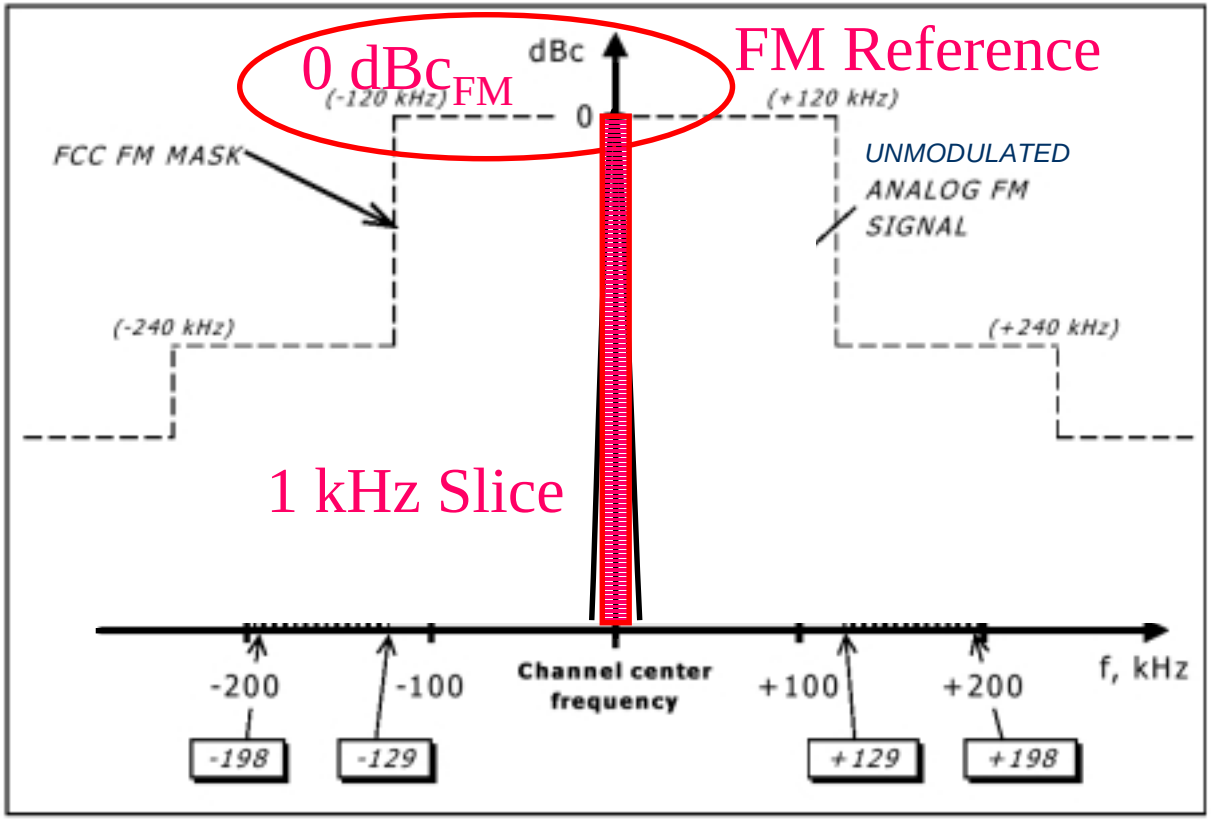
FCC Power Reference

47 CFR 73.317

FM transmission system requirements

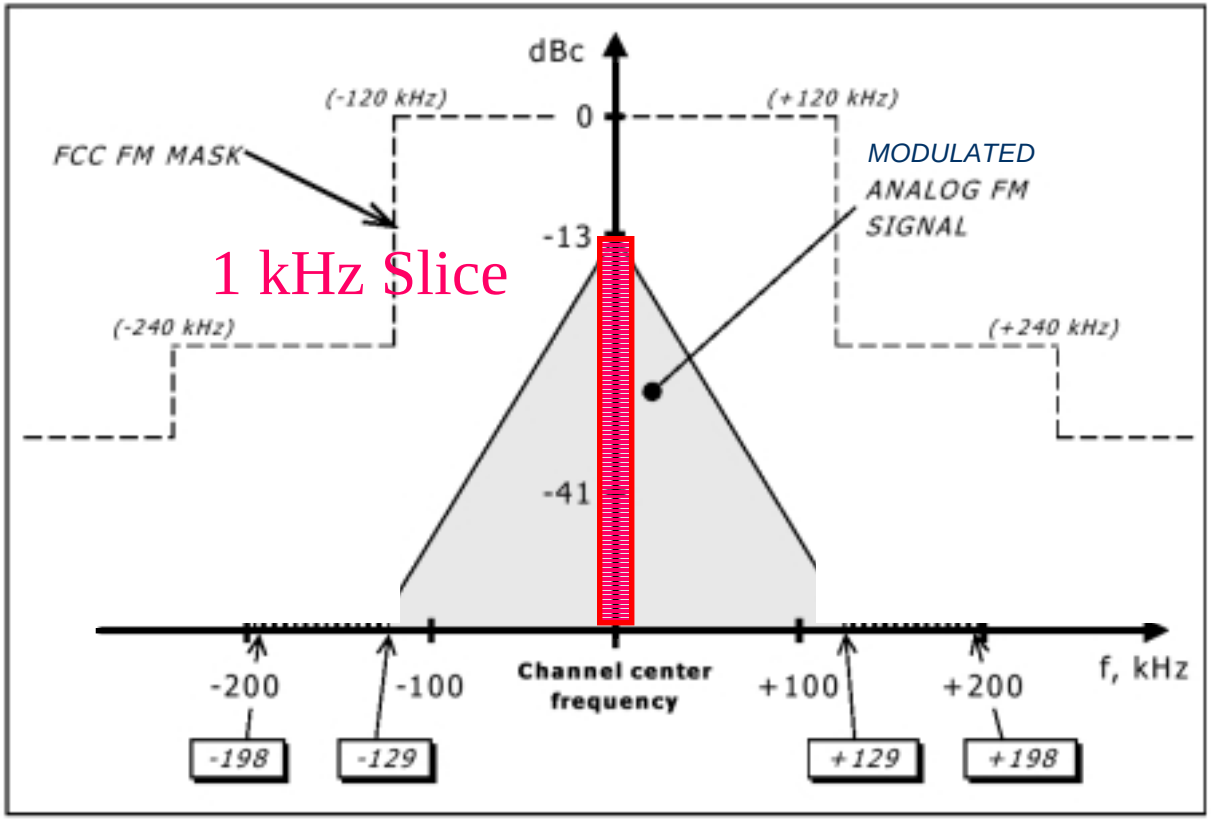
(b) Any emission appearing on a frequency removed from the carrier by between 120 kHz and 240 kHz inclusive must be attenuated at least 25 dB below the level of the unmodulated carrier. Compliance with this requirement will be deemed to show the occupied bandwidth to be 240 kHz or less.

Analog Power



Underlying Graphic From NRSC

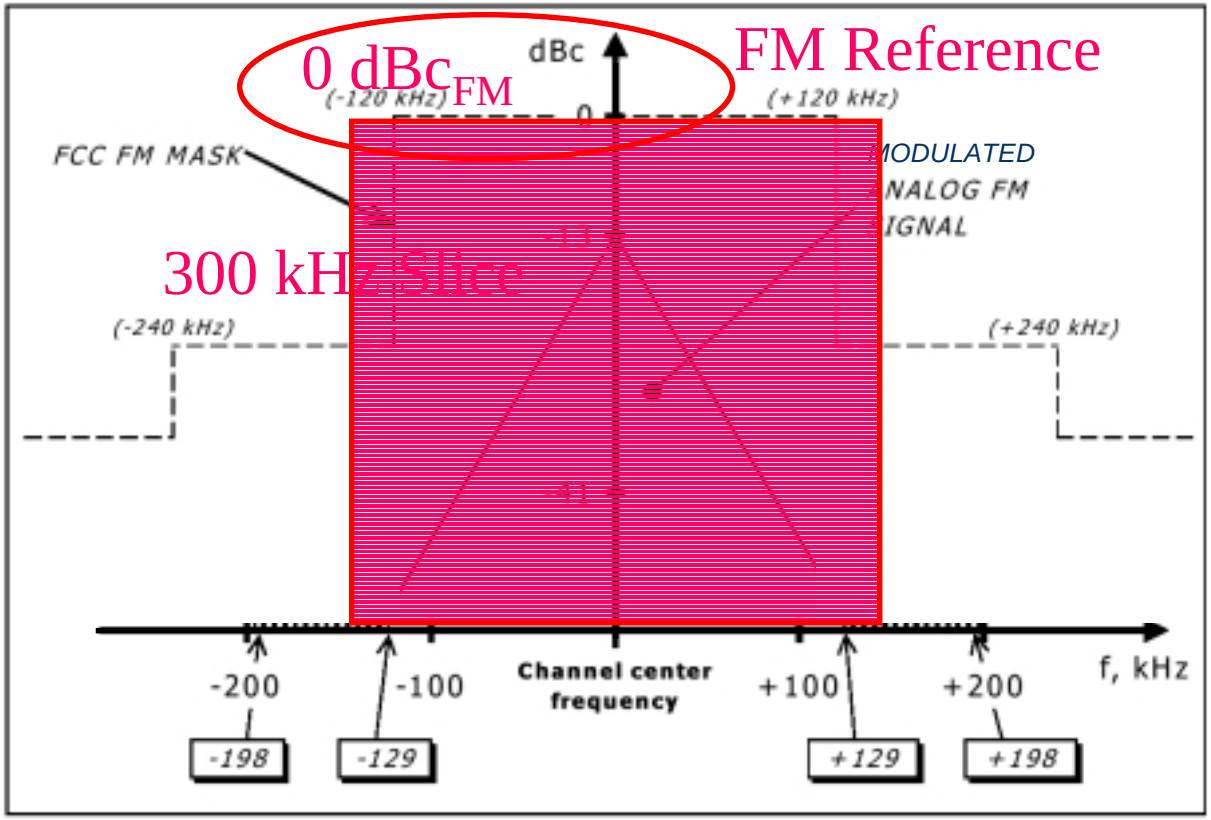
Analog Power



Analog Power

- Often not convenient to interrupt modulation to set reference
- If so: Recommend 300kHz bandwidth
  - Common RBW on spectrum analyzers
  - FM energy within 300 kHz B/W
  - Undesired energy normally outside this B/W
  - Experience shows reliable results

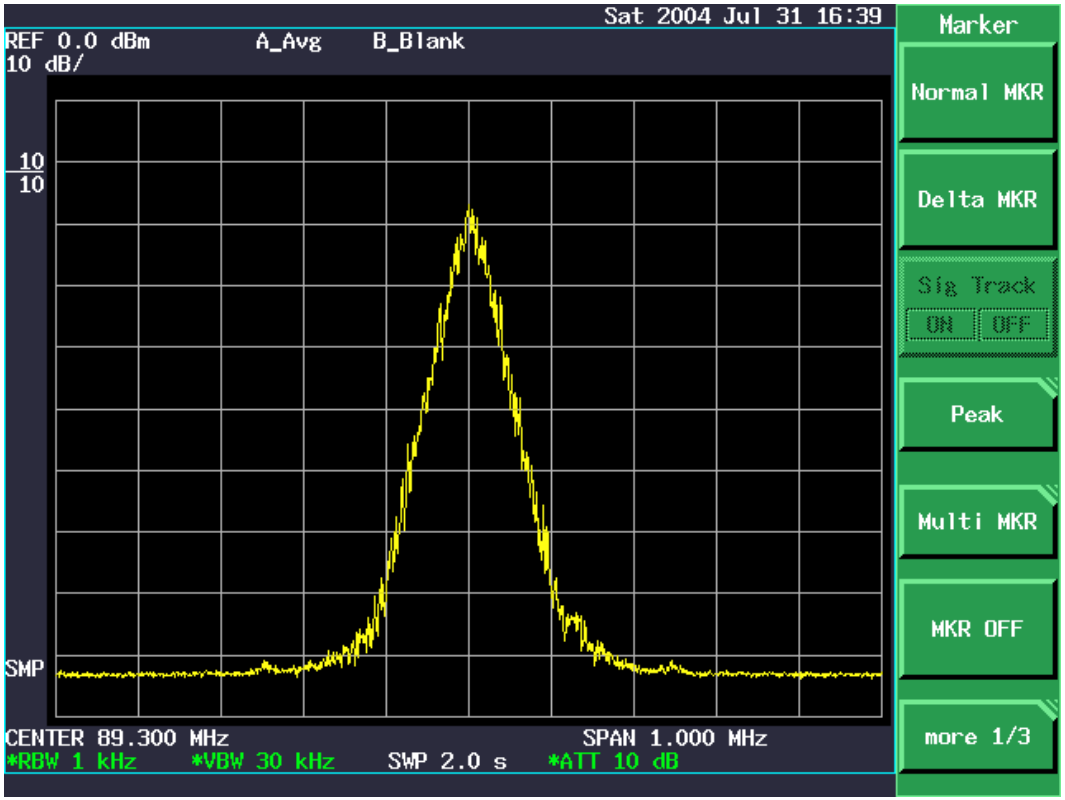
Analog Power



Measurements

- KUVO

FM only



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Analog FM Spectral Mask

- 47 CFR 73.317
  - (b) 120 – 240 kHz -25 dBc_{FM}
  - (c) >240 – 600 kHz -35 dBc_{FM}
  - (d) >600 kHz -80 dBc_{FM} (or –43-10 log(W ERP))

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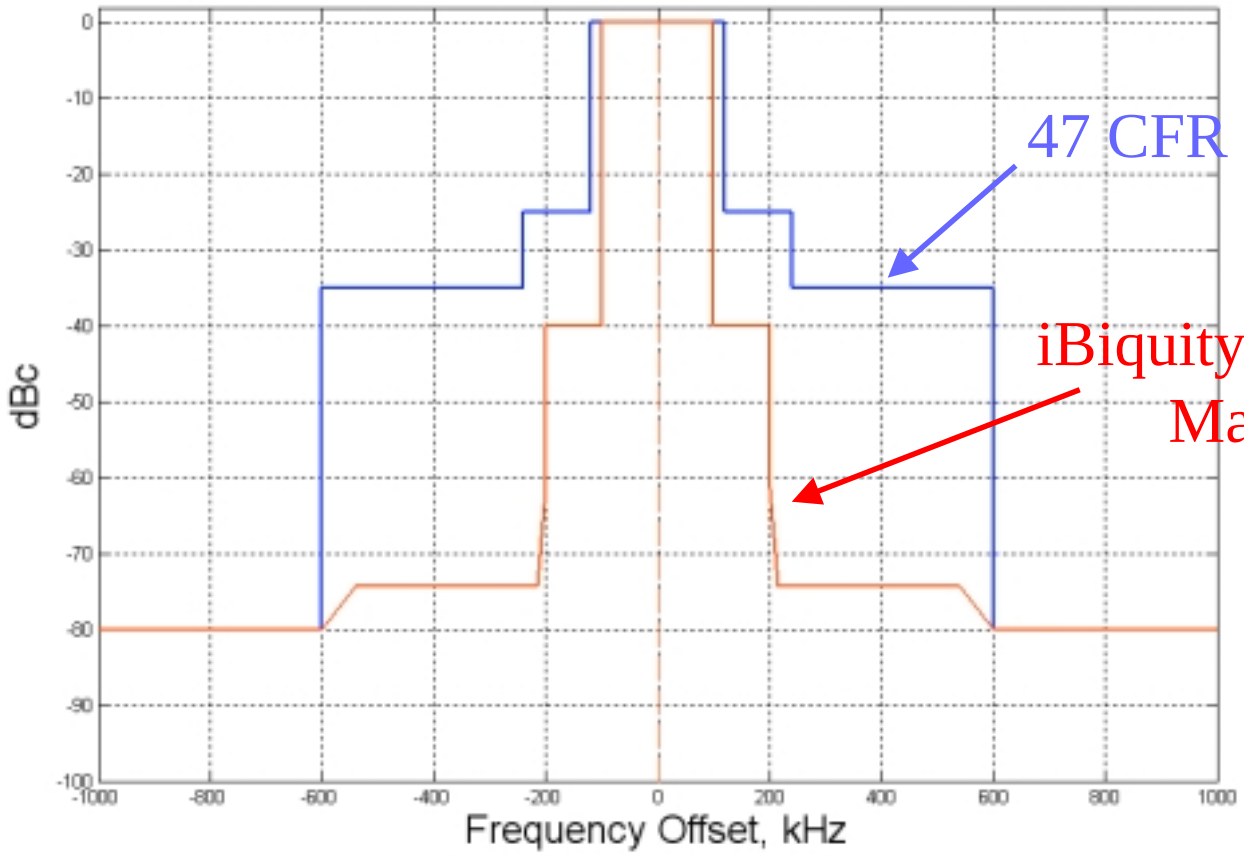
FCC Analog FM Mask and iBiquity Hybrid Mask



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iBiquity Hybrid Spectral Mask

- " For hybrid systems, measurements of the combined analog and digital signals shall be made by averaging the power spectral density of the signal in a 1 kHz bandwidth over a 30-second segment of time."

from HD Radio™ FM Transmission System Specifications, Rev. C, September 9, 2004

Digital Power

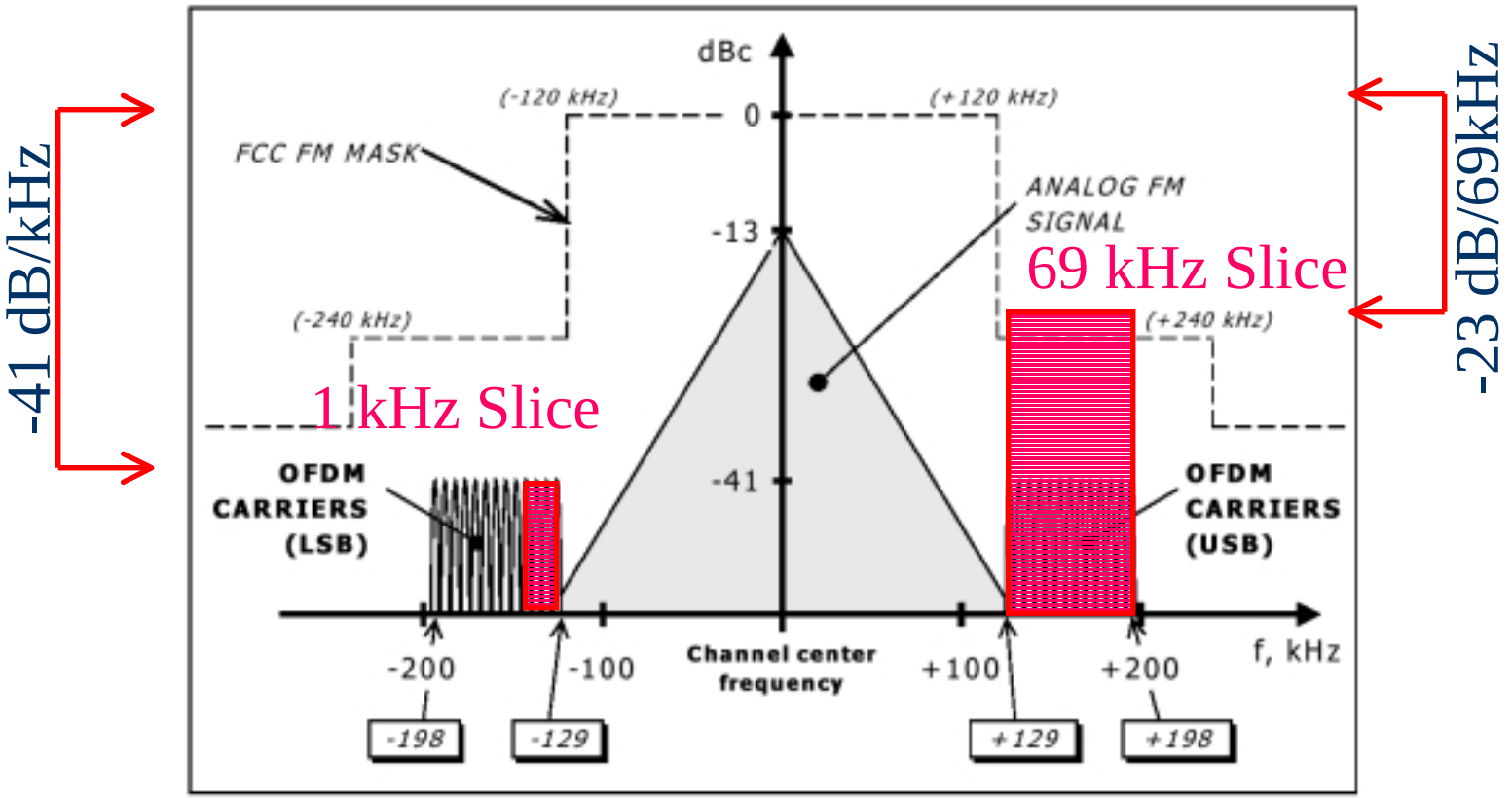


Figure 1. iBiquity FM IBOC system signal spectral power density

Digital Power

- IBOC “sidebands”
  - Primary Main
    - ±129 to 198 kHz (69 kHz band, each side)
    - 191 Orthogonal Frequency Division Multiplexing (OFDM) carriers on each sideband
  - Primary Extended
    - ±102 to 129 kHz
    - Up to 76 OFDM carriers on each sideband

Digital Power

- IBOC “sidebands”
  - OFDM Carriers , QPSK modulation
    - Spacing per carrier: 363.4 Hz
    - Power per carrier: -45.8 dBc_{FM}
    - Power per kHz: -41.4 dBc_{FM}
    - Power per PM sideband: -23 dBc_{FM}
    - Total PM power: -20 dBc_{FM}

Measurements

- Spectrum Analyzer
  - Variations among detection modes
    - "Sample"
      - Random sample in each "bin"
      - Average of series of random samples (by averaging n sweeps)
    - "Max-Min"
      - Average Max and Min values in successive sweeps
    - Video filtering
    - Peak

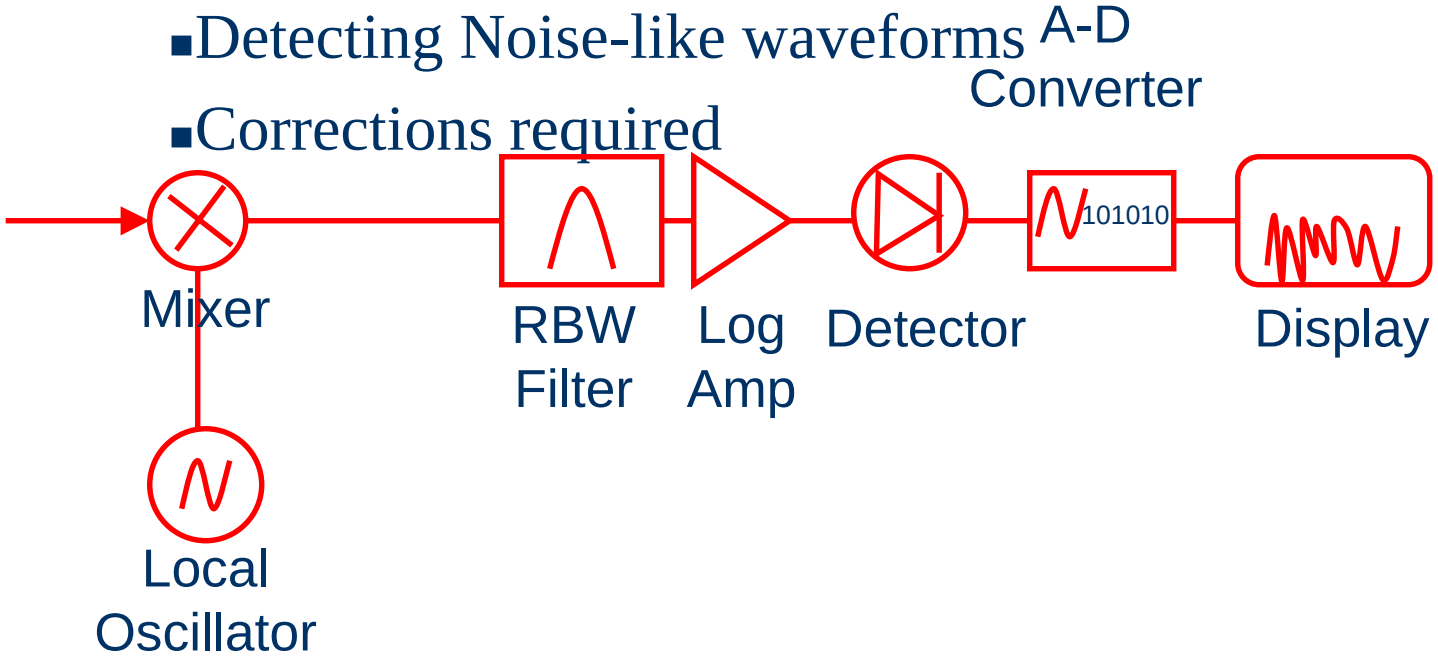
Measurements

- Analyzer Accuracy
  - OFDM is noise-like
  - Detecting noise-like waveforms
    - Average of filtered noise can be expected to be 1.05 dB less than the RMS
    - Log detection of filtered noise can be expected to under report level by additional 1.45 dB
    - Effective Noise Bandwidth of RBW filters affects results, typically ± tenths of a dB to 1.5 dB

- Sources: Agilent, Tektronix application notes

Typical Analyzer

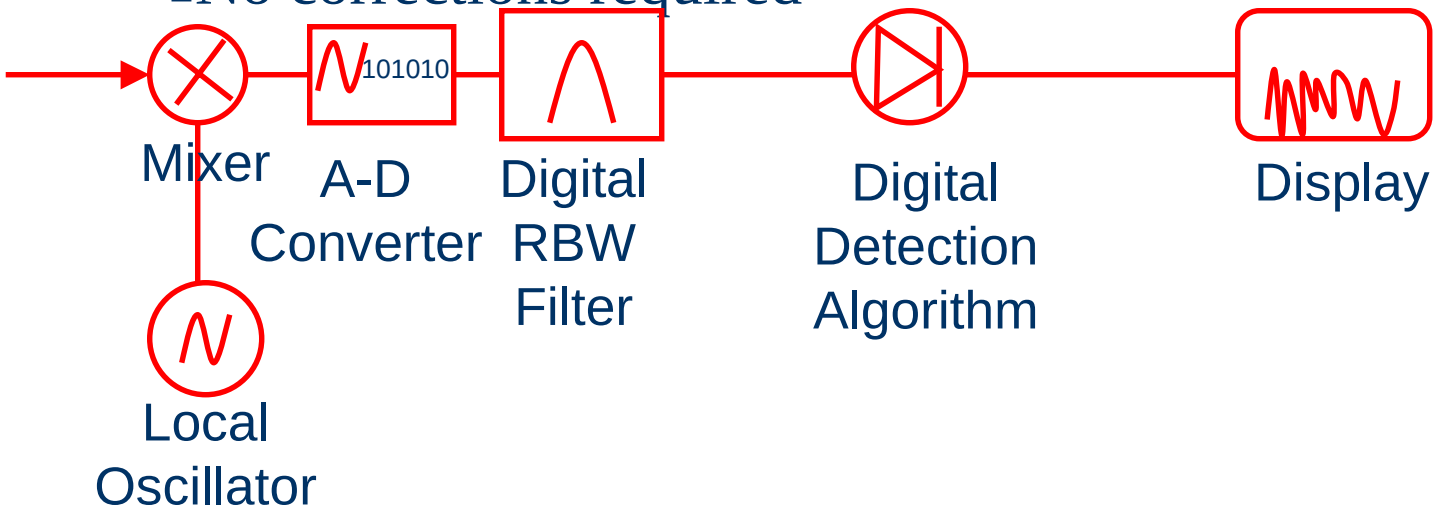
- Analyzer Accuracy
  - Detecting Noise-like waveforms
  - Corrections required



After Agilent PN 4395/96-1

Analyzer – Digital IF

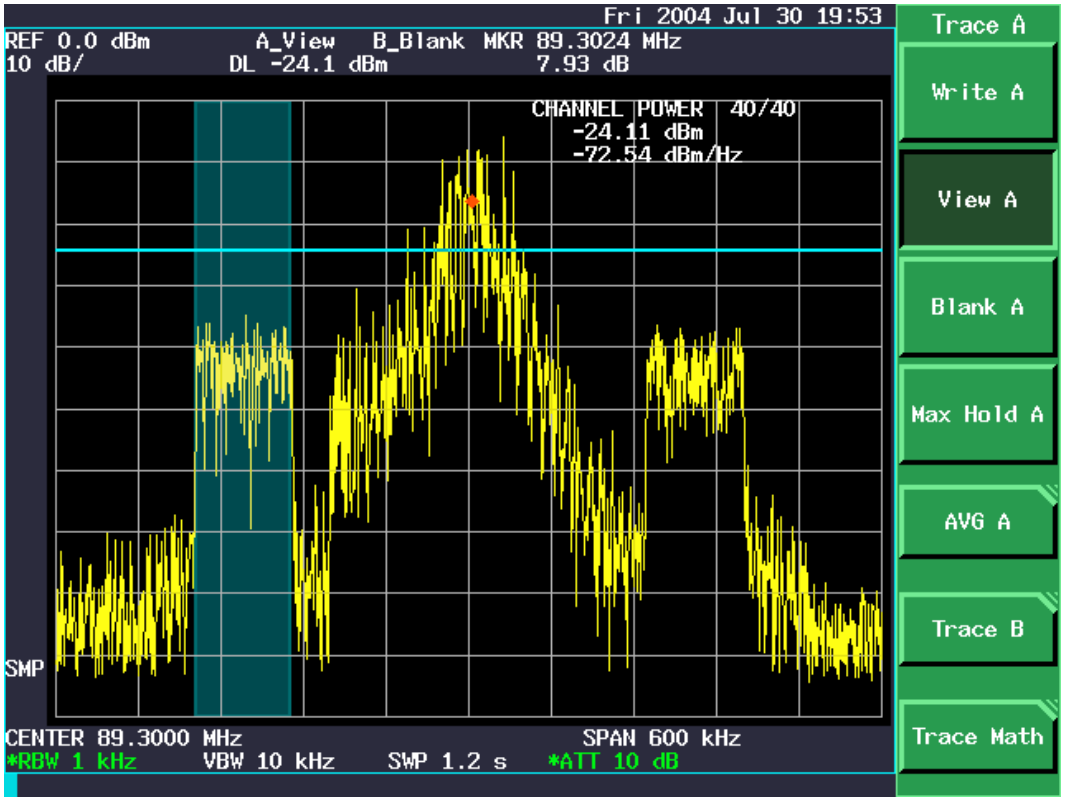
- Analyzer Accuracy
  - Detecting Noise-like waveforms
  - No corrections required



After Agilent PN 4395/96-1

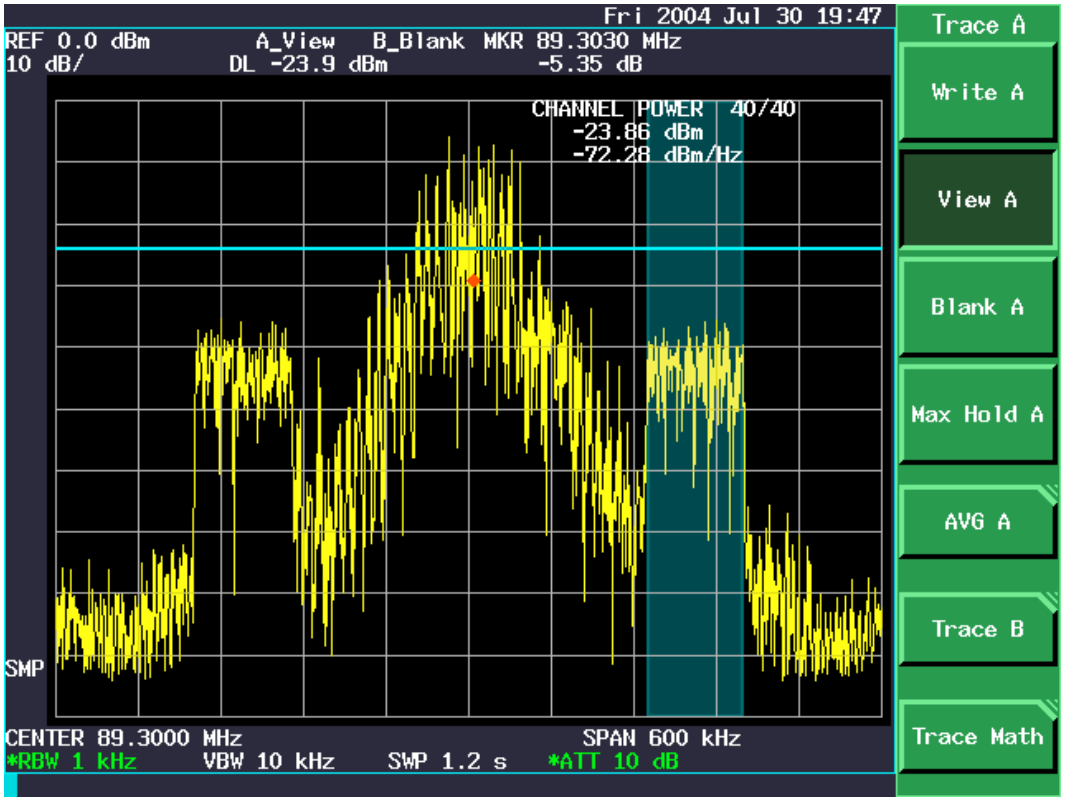
Measurements

- Channel Power
  - Analyzer utility
  - Computes power in a bandwidth
  - -24.11 dBc_{FM} per 69 kHz



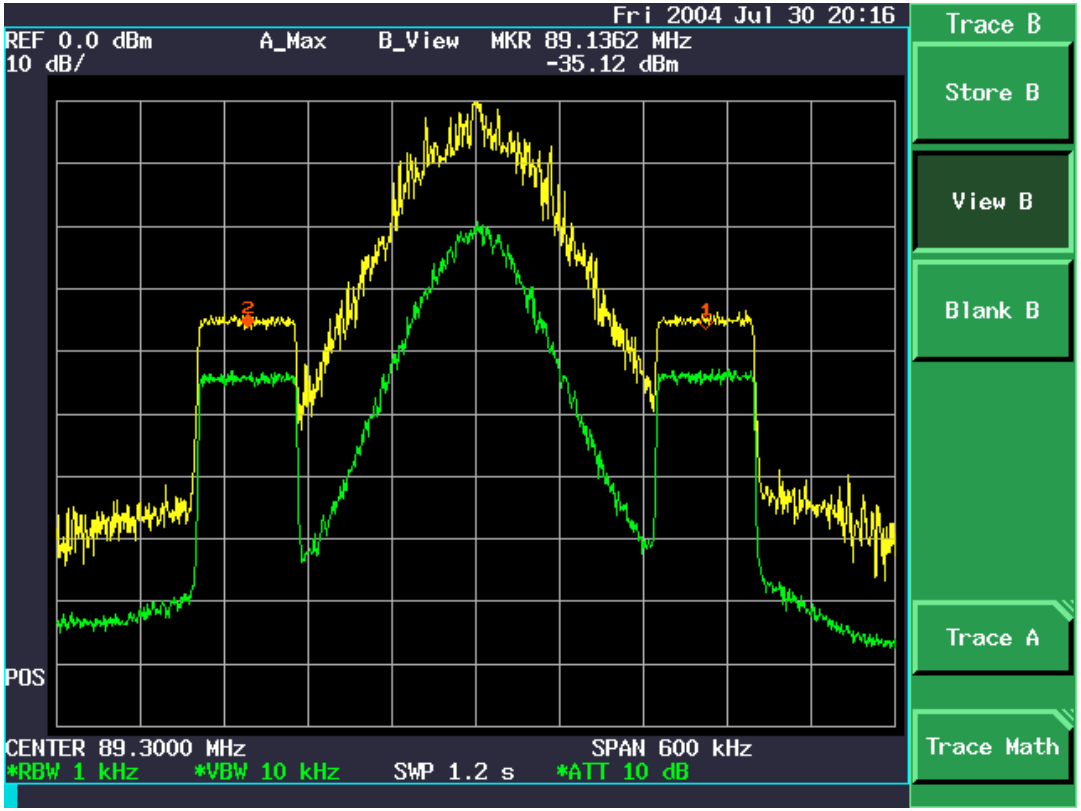
Measurements

- Channel Power
  - Analyzer utility
  - Computes power in a bandwidth
  - -23.86 dBc_{FM} per 69 kHz



Measurements

- Positive Peaks
  - Peak Hold
- Sample
  - Averaged
  - -42.8 to –44.3 dBc_{FM}/kHz



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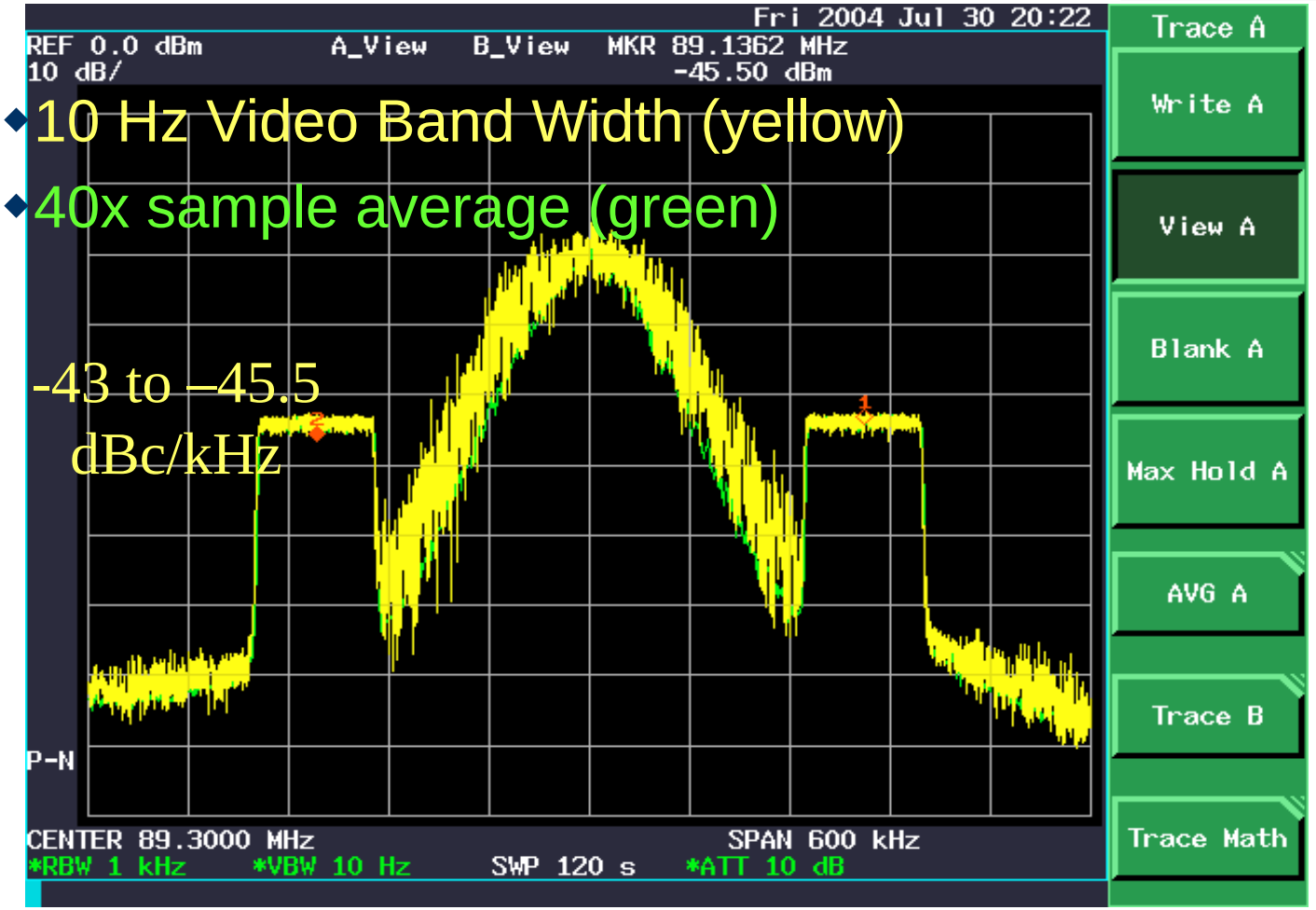
Measurements



- 10 Hz Video Band Width (yellow)
- 40x sample average (green)

-43 to –45.5 dBc/kHz

Interference Potential

- IBOC Primary Main “subcarriers”
  - Linear amplification
  - Push transmitter into compression
    - For more efficiency
    - Reduces hardware cost per watt
  - With compression comes intermodulation
    - “Spectral regrowth”

Interference Potential

Transmitter with pre-correction disabled

Primary Main IBOC at ± 164 kHz

Regrowth at +492 kHz;

At +820 kHz

OFDM Carriers in same group interact with each other

Interference Potential

What Should this Ratio Be?

Interference Potential

Midpoints ±164 kHz

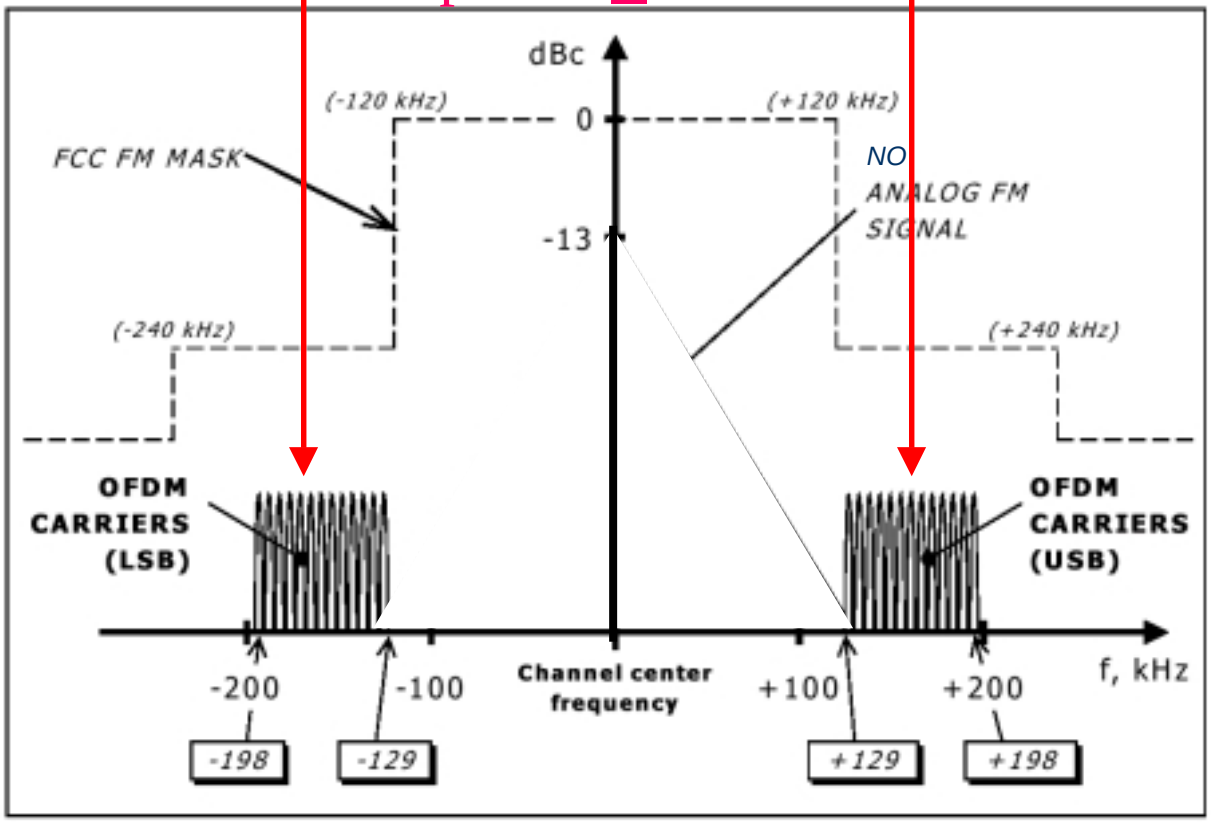
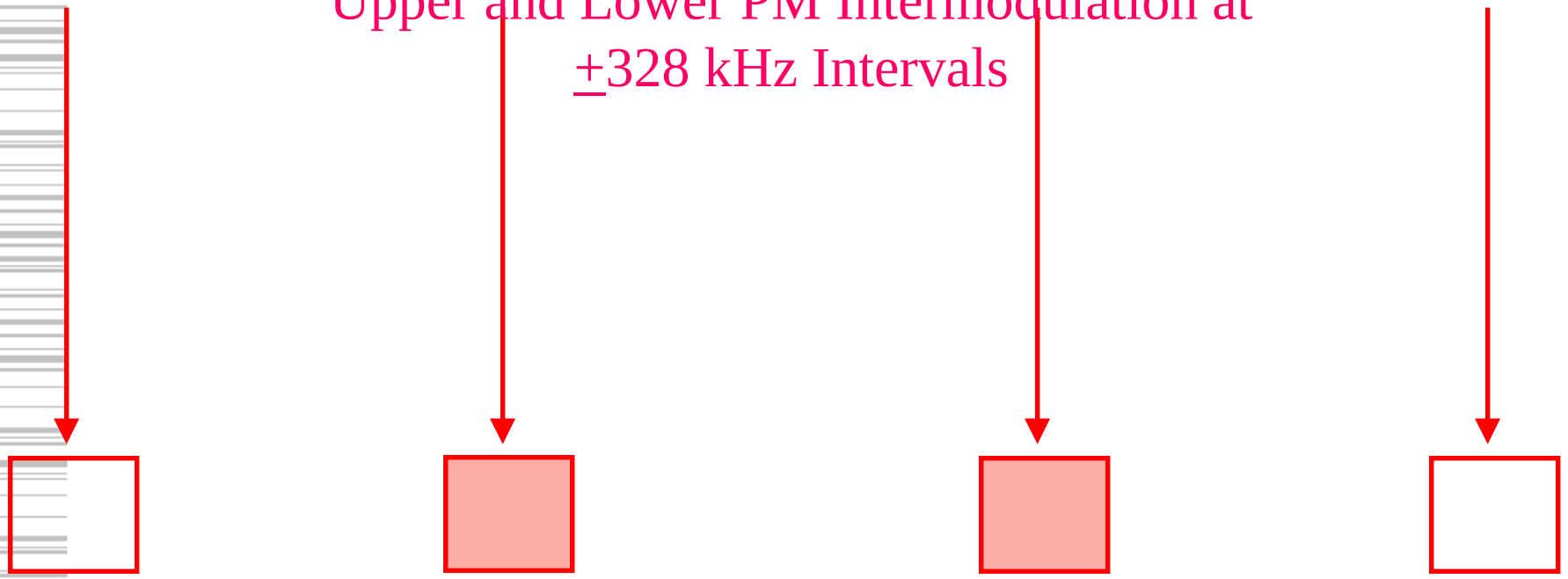


Figure 1. iBiquity FM IBOC system signal spectral power density

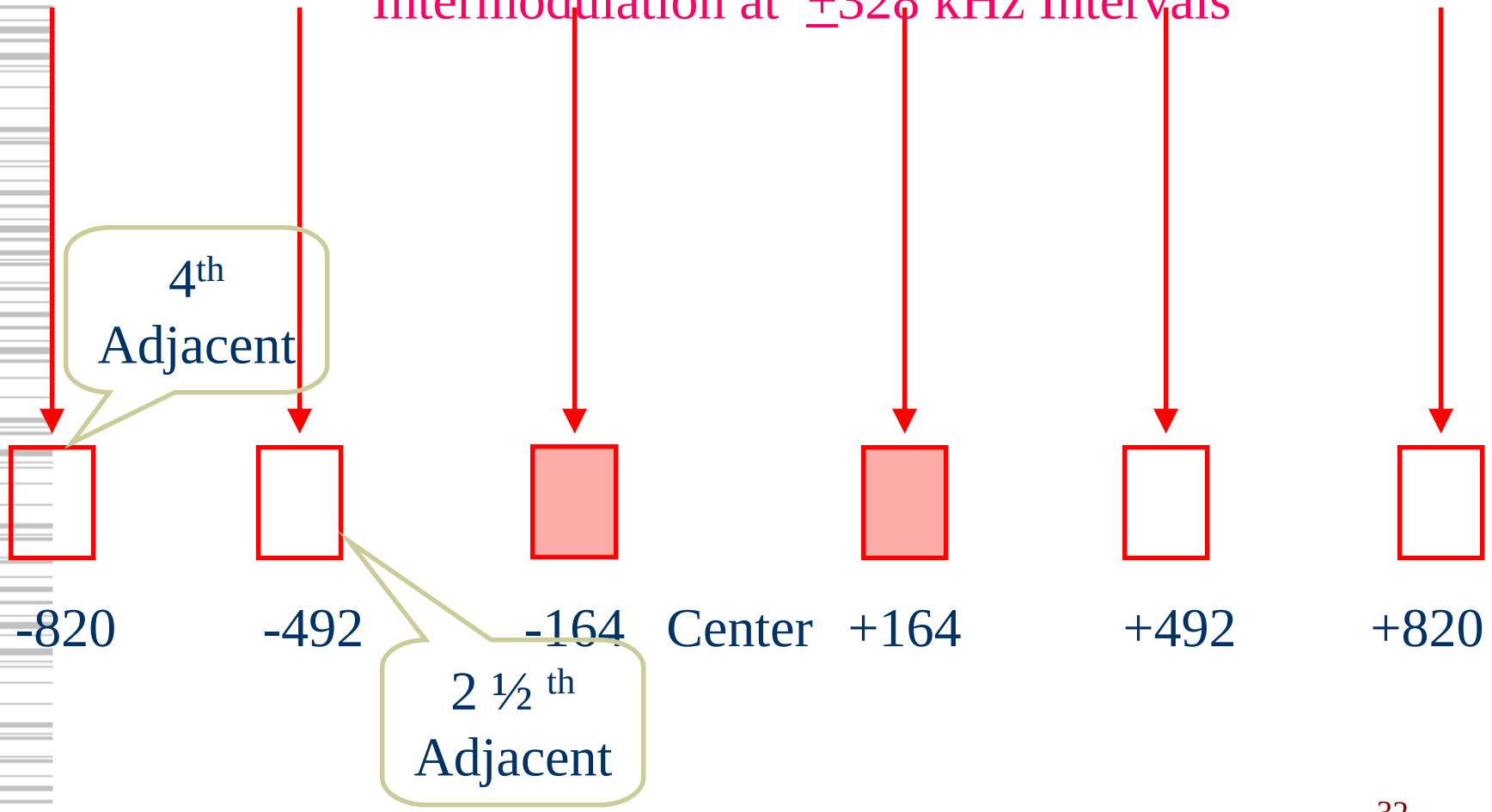
Interference Potential

Upper and Lower PM Intermodulation at ±328 kHz Intervals



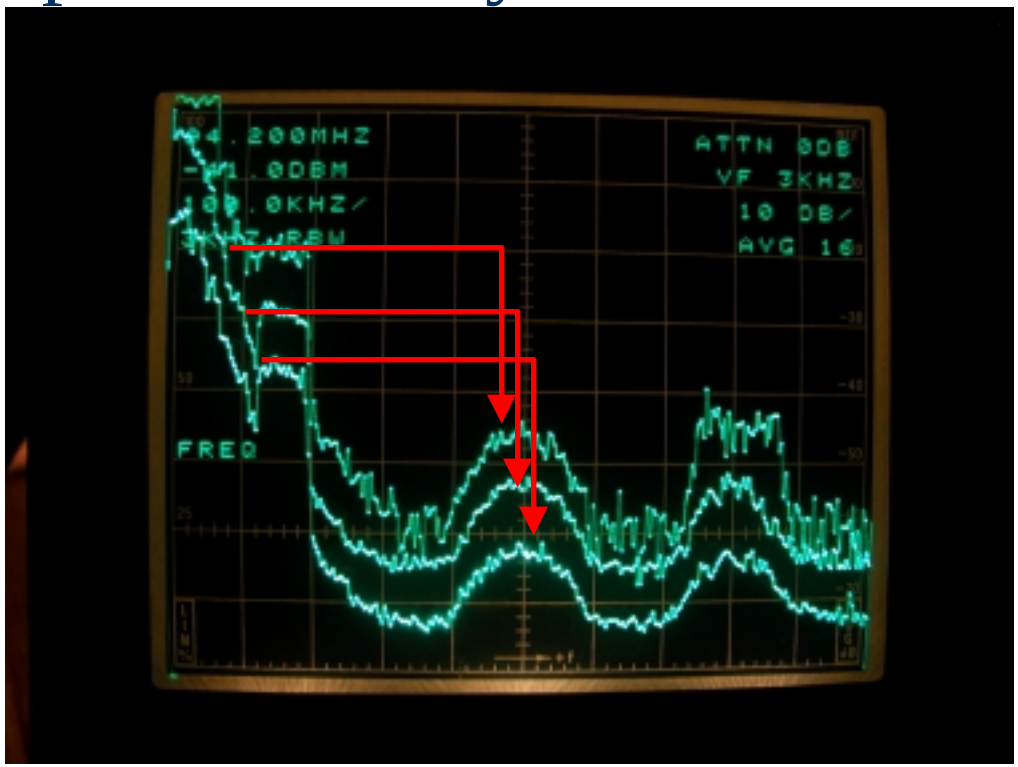
Interference Potential

Intermodulation at ±328 kHz Intervals



Measurements

- Spectrum analyzers



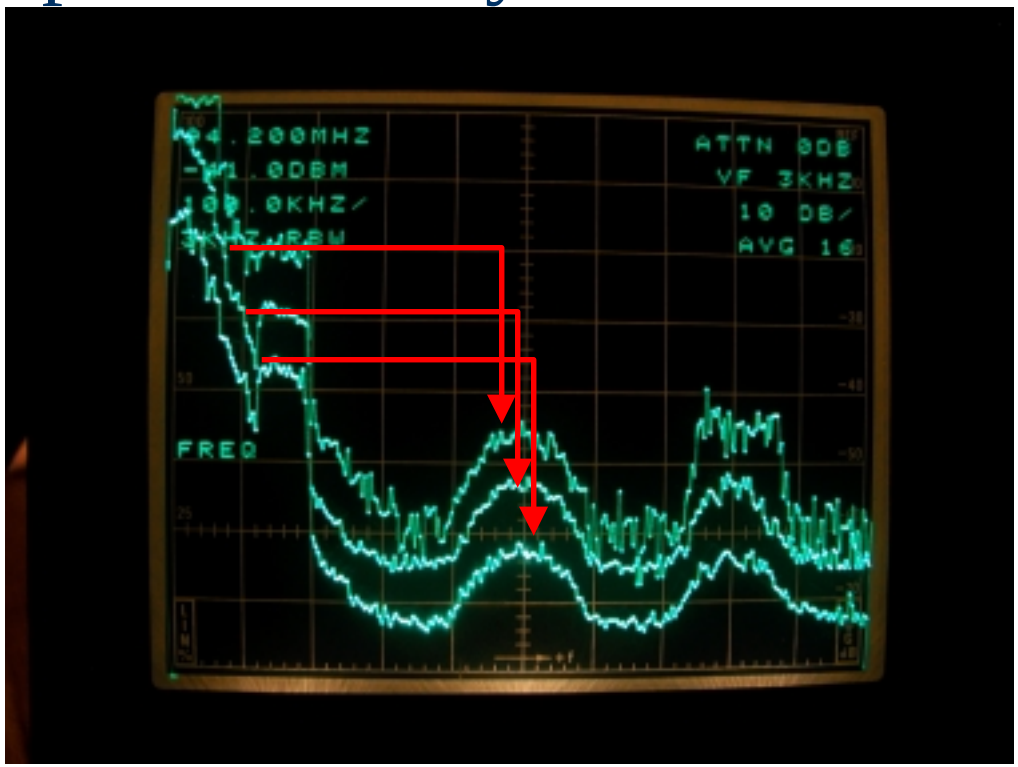
Peak Hold

Peak Average

Max-Min Average

Measurements

- Spectrum analyzers



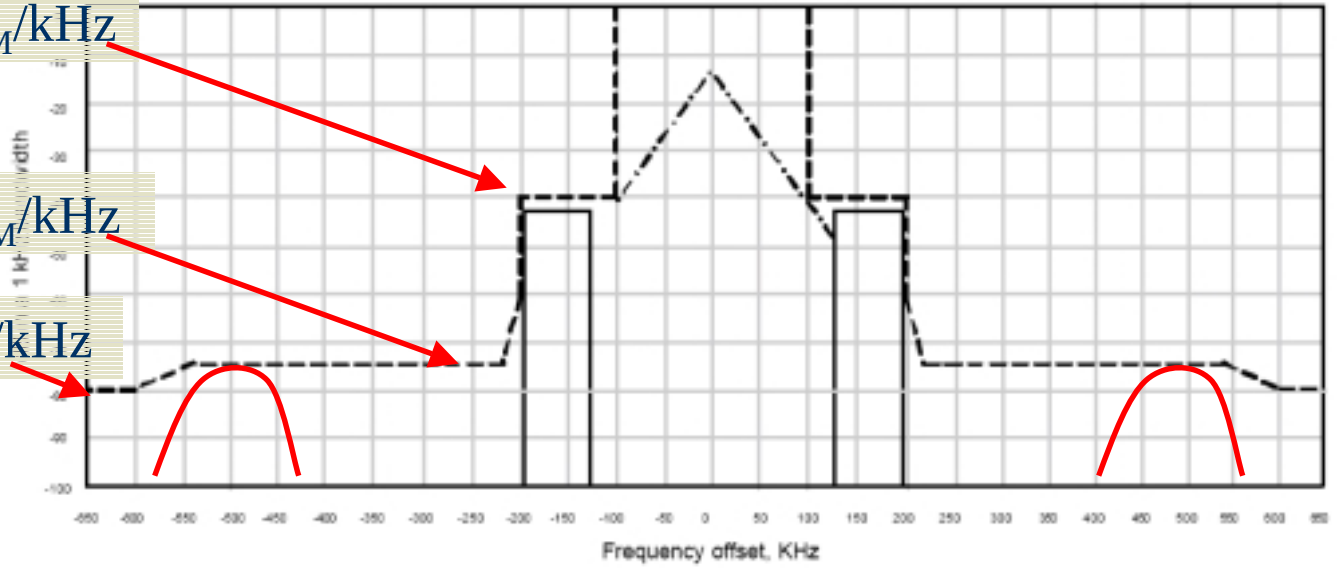
Any accumulation mode shows relation between PM and regrowth

iBiquity RF Mask

-40 dBc$_{FM}$/kHz

-74.4 dBc$_{FM}$/kHz

-80 dBc$_{FM}$/kHz



Frequency, F, Offset Relative to Carrier	Level, dB/kHz
200-215 kHz offset	[-61.4 - (|frequency in kHz|-200 kHz) · 0.867] dB
215-540 kHz offset	-74.4 dB
540-600 kHz offset	[-74.4 - (|frequency in kHz|-540 kHz) · 0.093] dB
>600 kHz offset	-80 dB

Table 3: iBiquity FM Hybrid Mode Noise and Spurious Emission Limits

iBiquity RF Mask

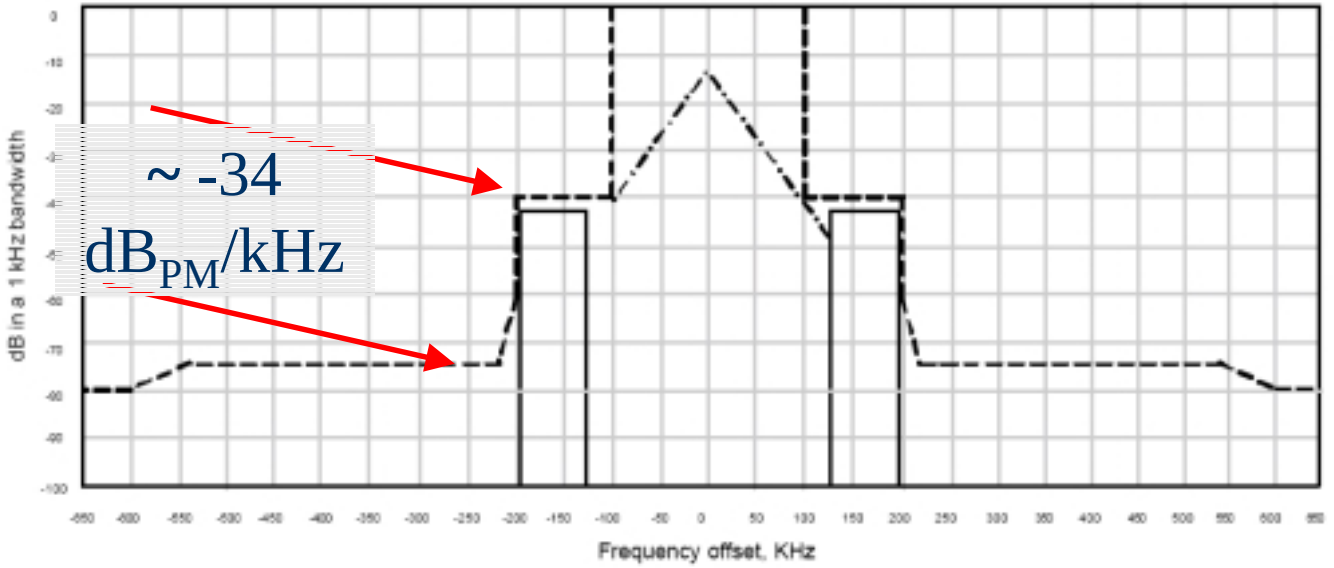


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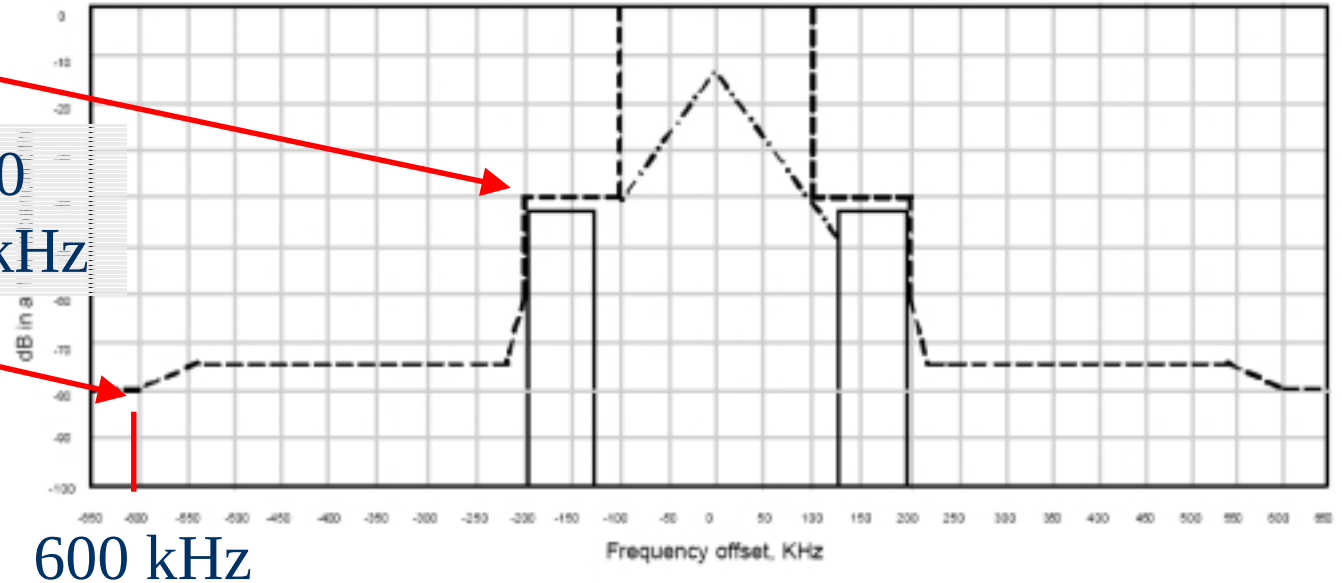
Table 3: iBiquity FM Hybrid Mode Noise and Spurious Emission Limits

iBiquity RF Mask

~ -40 dB_{PM}/kHz



600 kHz

Frequency, F, Offset Relative to Carrier	Level, dB/kHz
200-215 kHz offset	[-61.4 - (|frequency in kHz|-200 kHz) · 0.867] dB
215-540 kHz offset	-74.4 dB
540-600 kHz offset	[-74.4 - (|frequency in kHz|-540 kHz) · 0.093] dB
>600 kHz offset	-80 dB

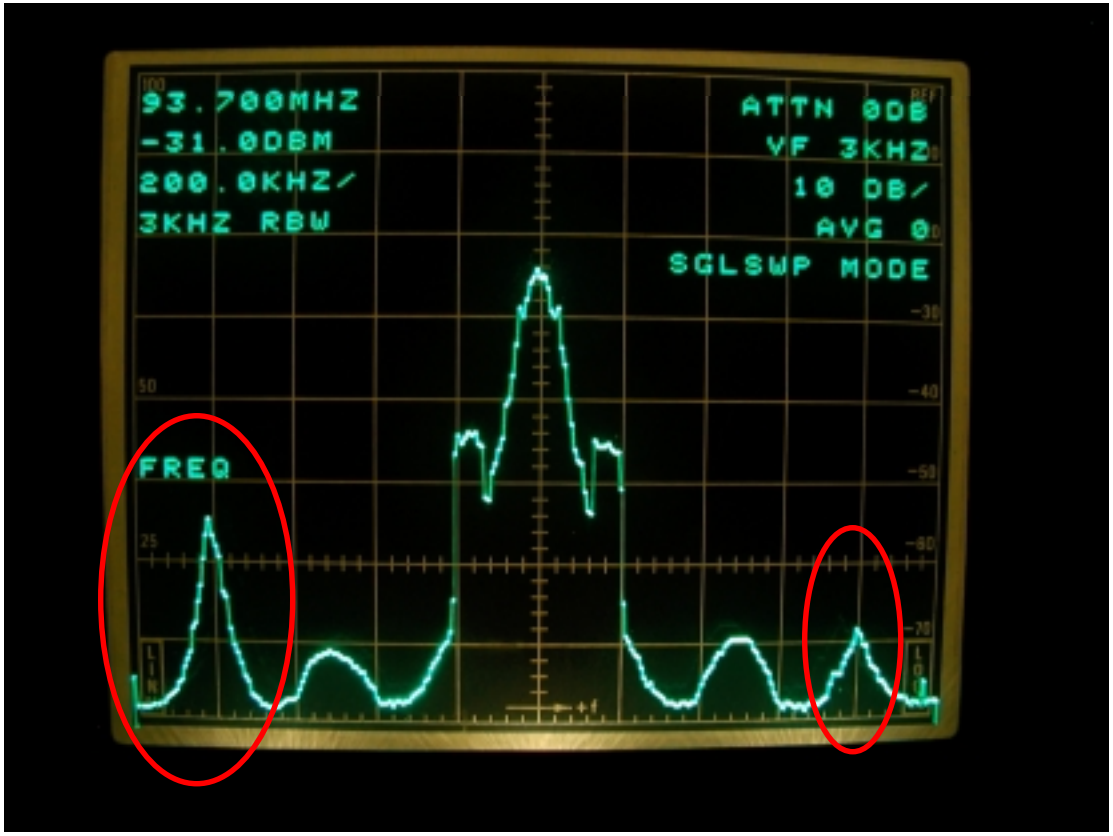
Table 3: iBiquity FM Hybrid Mode Noise and Spurious Emission Limits

This Proposed Mask is based on what is practicable, not necessarily on interference protection analysis

iBiquity Hybrid Spectral Mask

- iBiquity note under Table 4-1
- "The requirements for noise and spurious emission limits defined in this subsection reflect acceptable performance criteria. In certain circumstances, additional measures (filtering, active emissions suppression, etc.) may be needed to reduce the spectral emissions below the limits given in this subsection in order to reduce mutual interference between broadcast stations."

Why Regrowth Matters



Field Measurement with 4th Adjacent Signals

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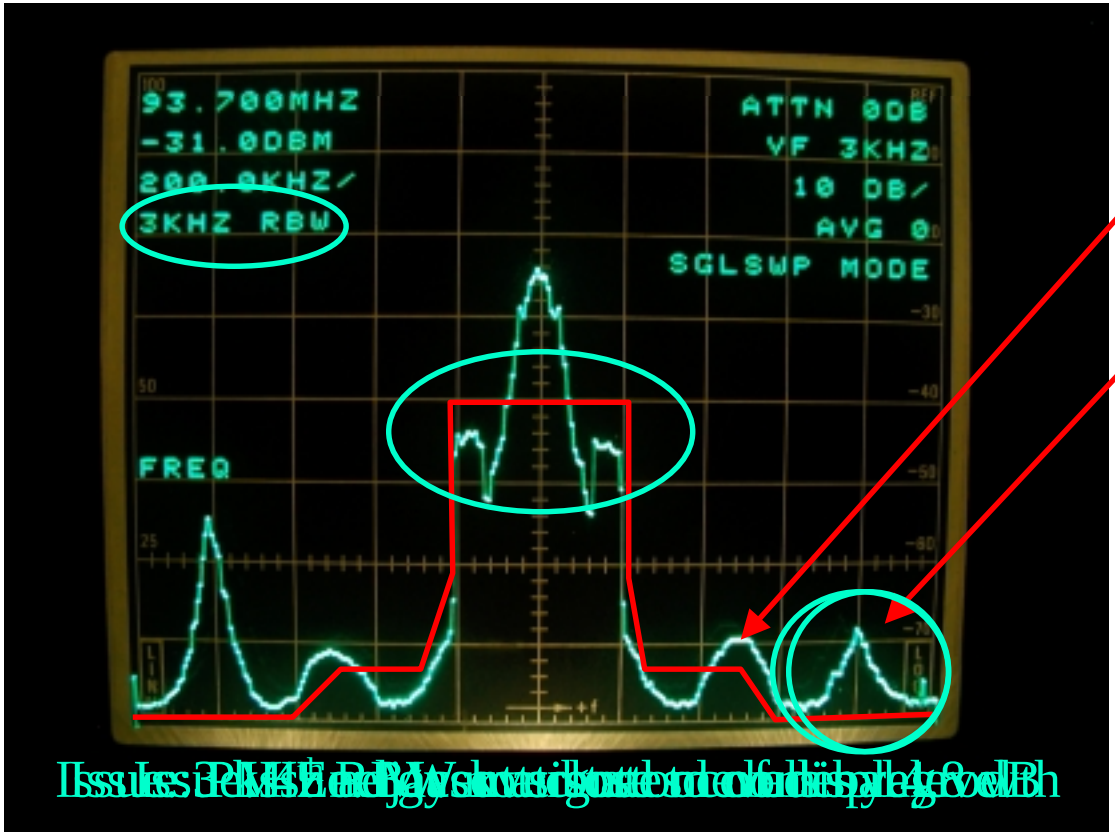
What's Wrong with this Picture?



Should Be
< –74.4 dBc_{FM}
in 1kHz

Should Be
< –80dBc_{FM}
in 1kHz

Separate Amplification

- Separate Amplification
  - Digital signal generated and amplified separately
    - Analog and digital run through combiner
      - "High Level Combining"
    - Analog and digital combined at antenna, or
    - Analog and digital on separate antennas
  - Regrowth primarily limited to 328-kHz intervals

Separate Amplification

Common Amplification

- Common Amplification
  - Analog Signal Amplified with Digital
  - More Points of Regrowth
    - Digital energy and analog energy intermodulate in common amplifier

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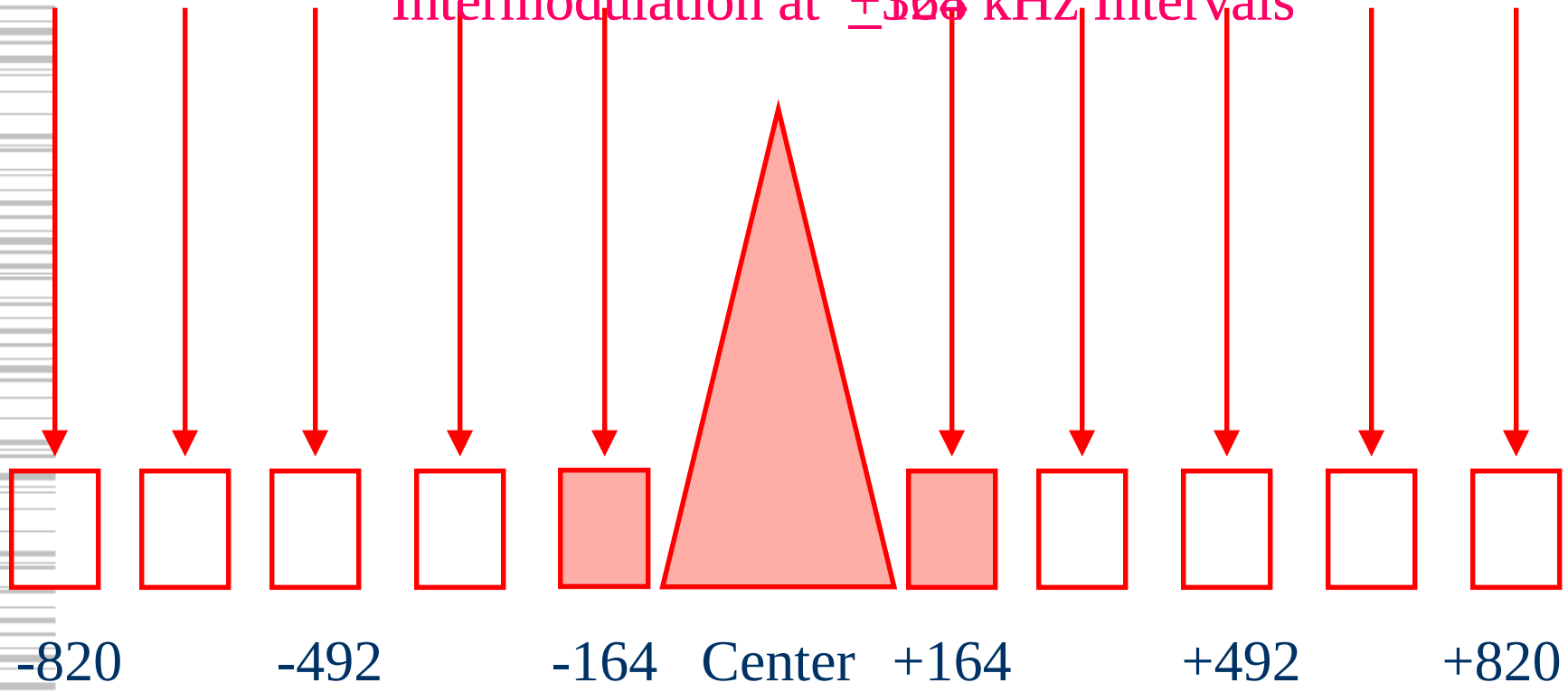
Common Amplification

Intermodulation at ±328 kHz Intervals



Precorrection

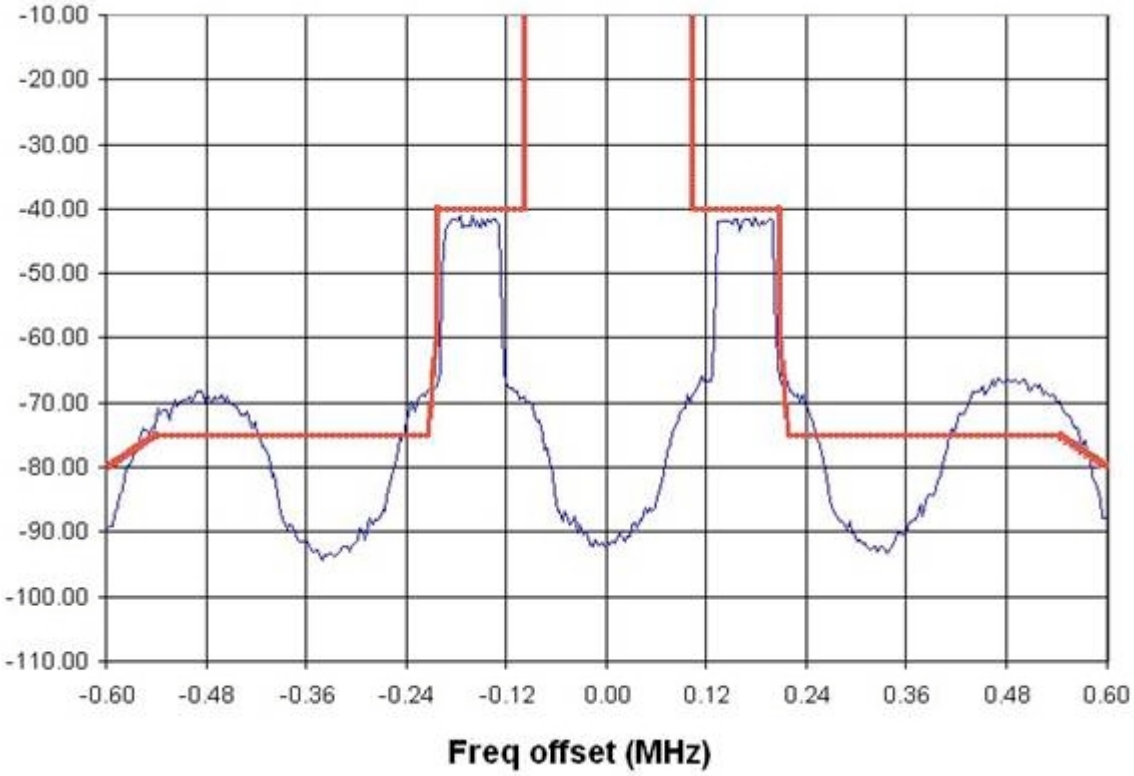
- Precorrection is Expansion
  - Anticipates the compression of the Power Amp
- What's the Opposite of "Compand"?
  - Compress-Expand = Compand
  - Expand-Compress = Express???? Empress????

Precorrection

- Compression Example:
  - A digital exciter without precorrection, measured 6-7 dB peak to average power ratio
  - After going through the PA, peak to average 4-5 dB

Precorrection

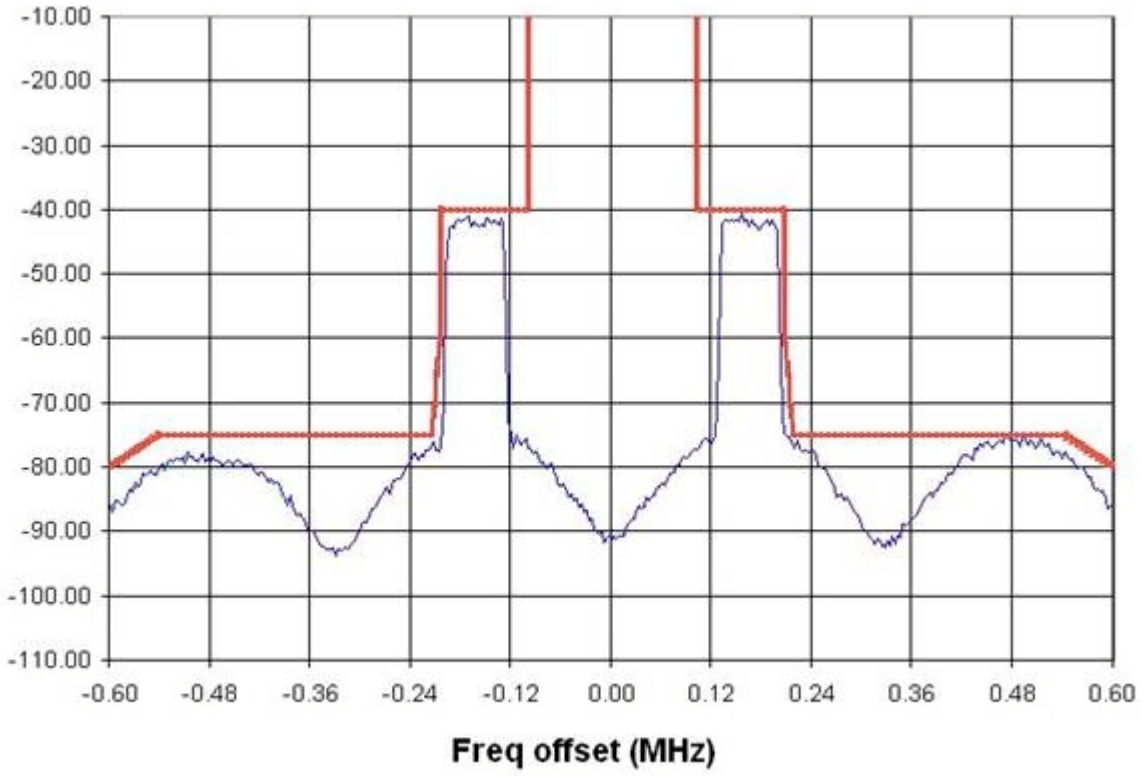
- Without precorrection



Courtesy Harris Corp.

Precorrection

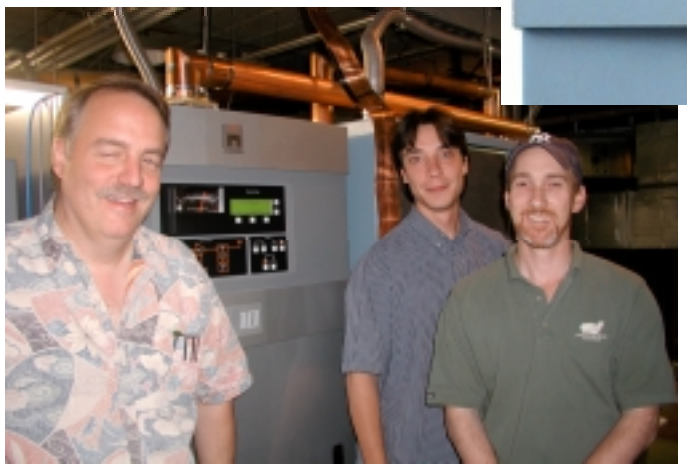
- With fixed precorrection



Courtesy Harris Corp.

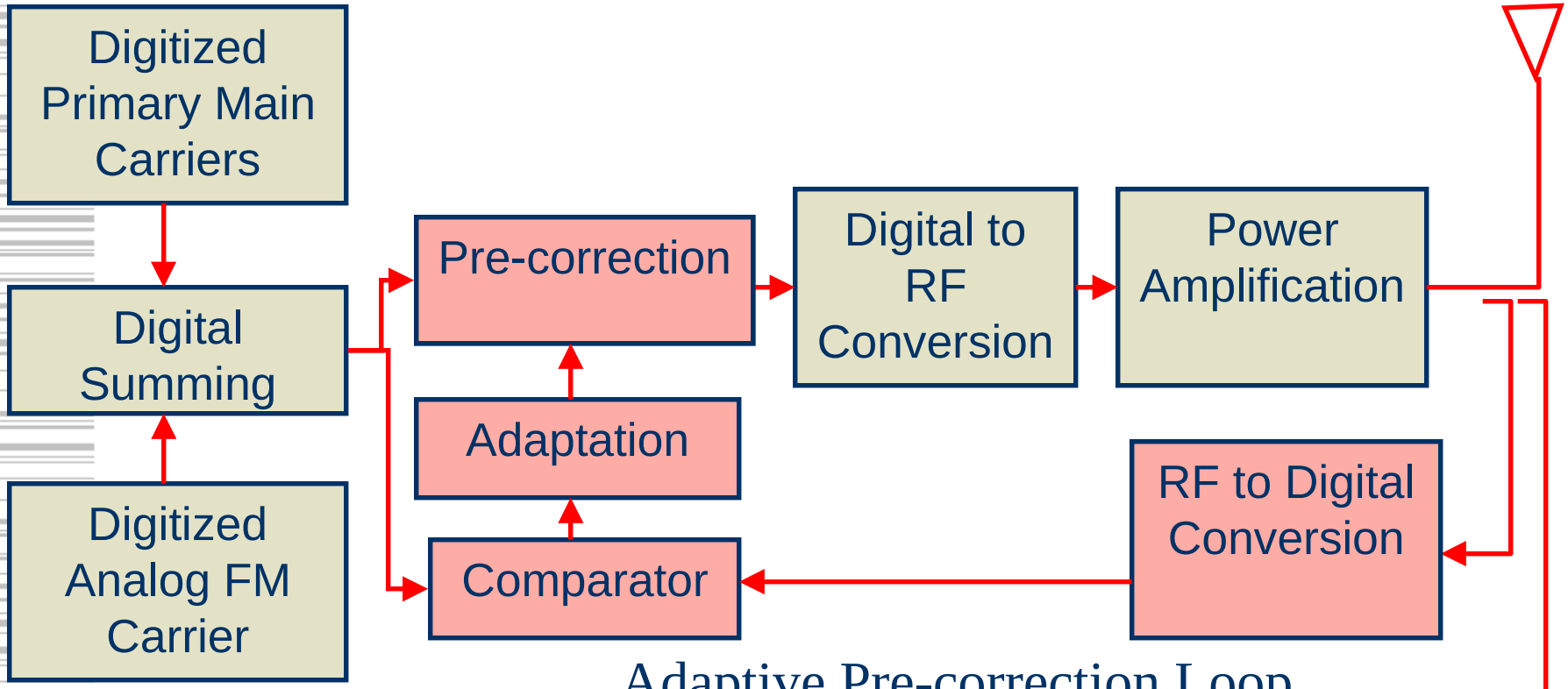
Adaptive Precorrection

- Case Study
  - KUVO, Denver
  - Nautel V-10 Transmitter

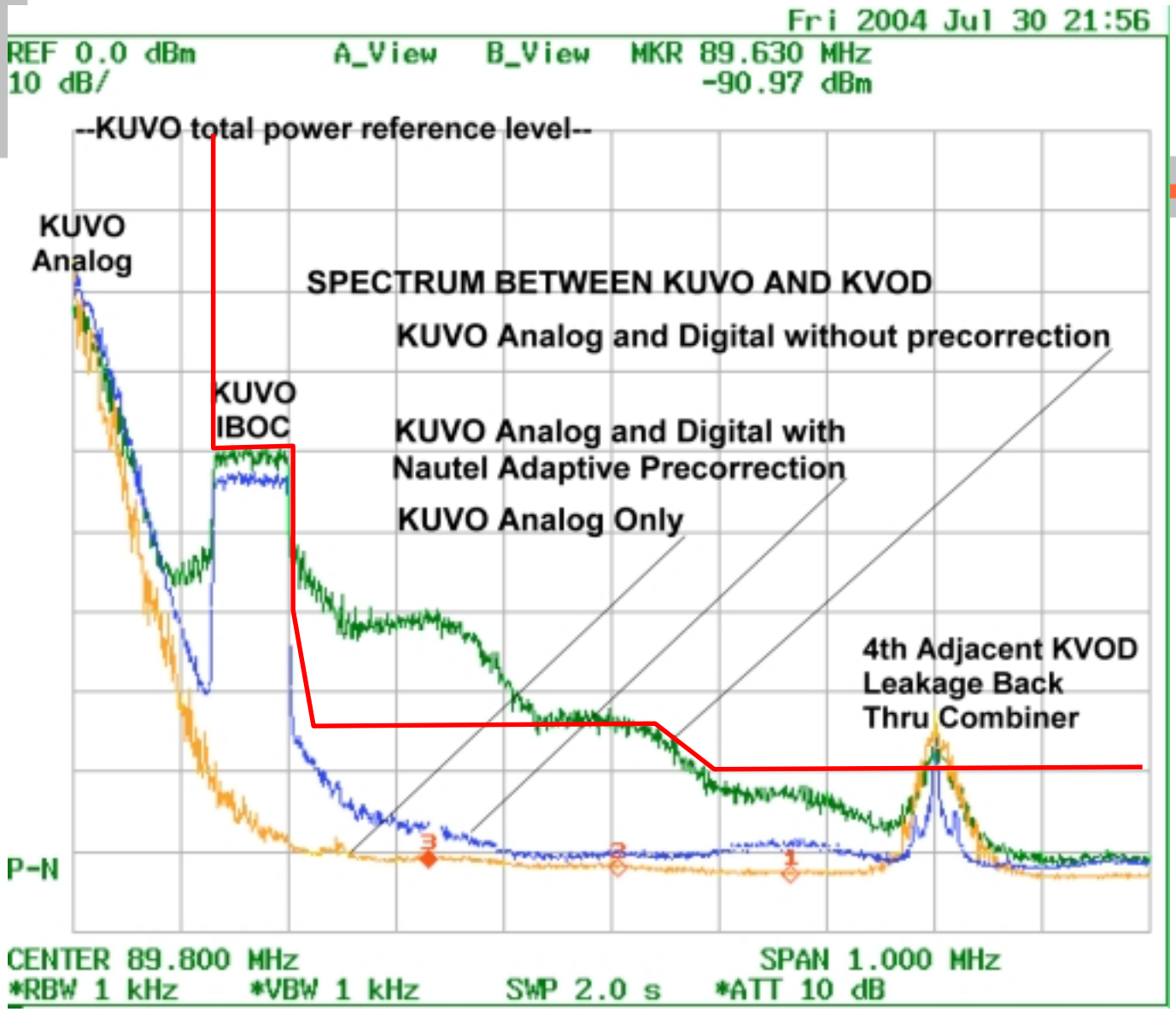


nautel

Adaptive Precorrection

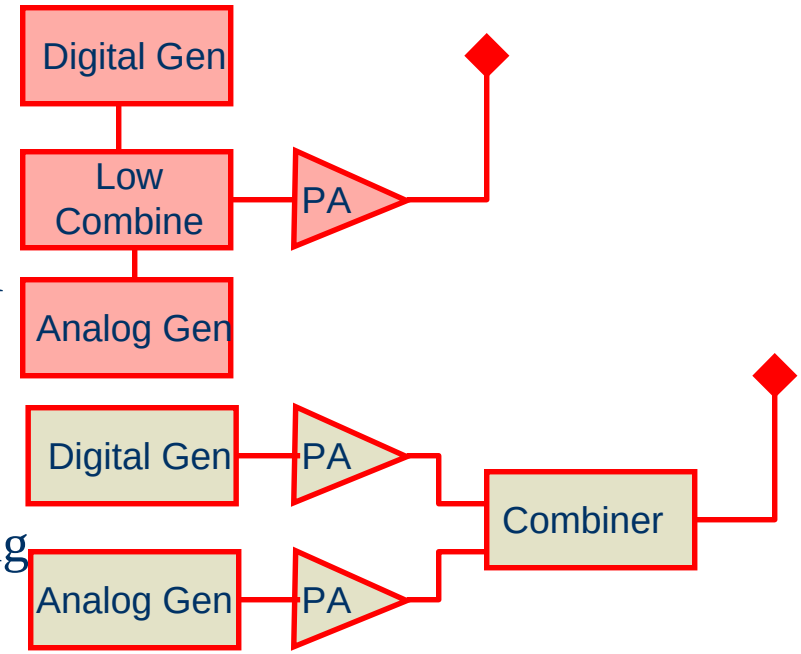


Adaptive Pre-correction Loop


Fri 2004 Jul 30 21:56
REF 0.0 dBm
10 dB/
A_View
B_View
MKR 89.630 MHz
-90.97 dBm
--KUVO total power reference level--
KUVO
Analog
SPECTRUM BETWEEN KUVO AND KVOD
KUVO Analog and Digital without precorrection
KUVO
IBOC
KUVO Analog and Digital with
Nautel Adaptive Precorrection
KUVO Analog Only
4th Adjacent KVOD
Leakage Back
Thru Combiner
P-N
CENTER 89.800 MHz
SPAN 1.000 MHz
*RBW 1 kHz
*VBW 1 kHz
SWP 2.0 s
*ATT 10 dB

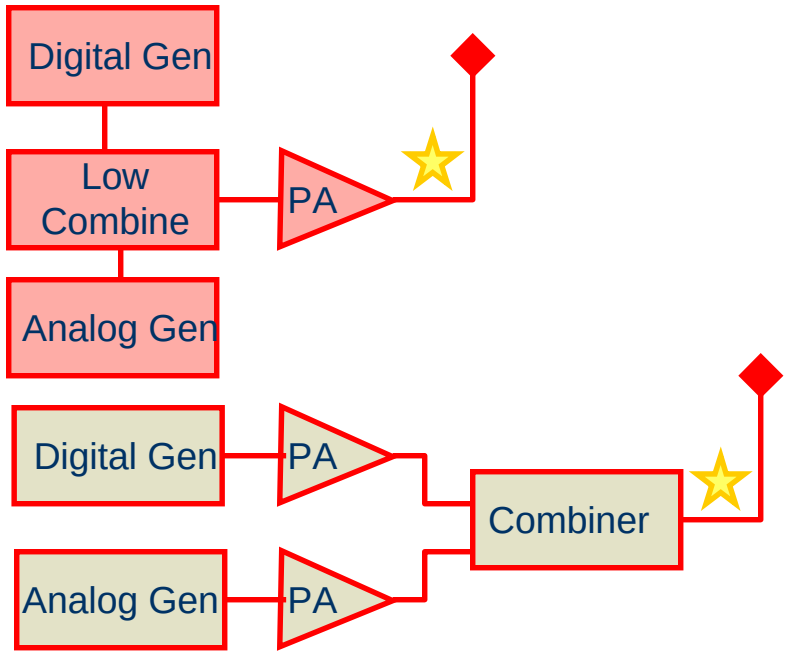
Common Line

- Analog and Digital exist together in the same transmission line prior to transmission from a common antenna
  - Low level combined
    - Common amplification
  - High Level Combined
    - Lossy hybrid combining
      - 10-dB combining
      - Split level combining



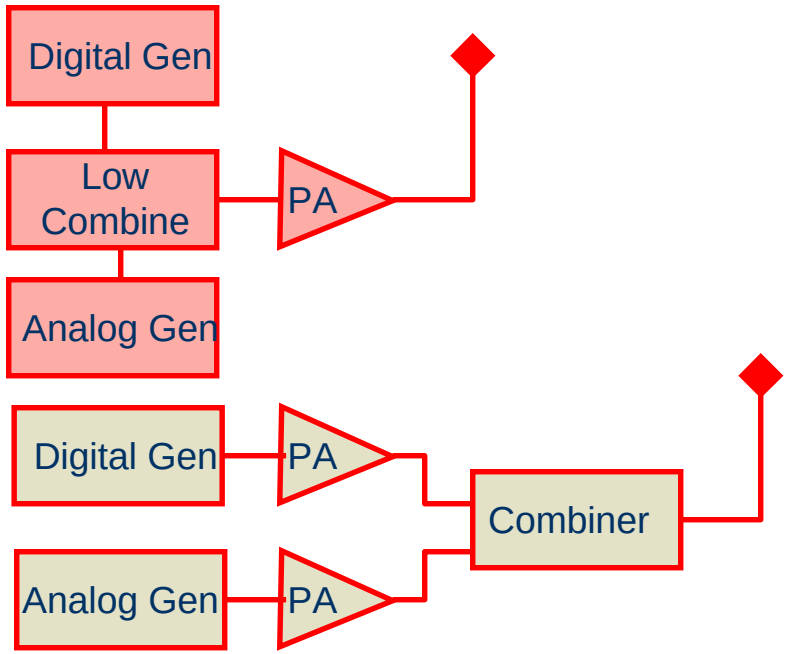
Common Line

- Sample points using directional couplers in transmission line
  - Common Line



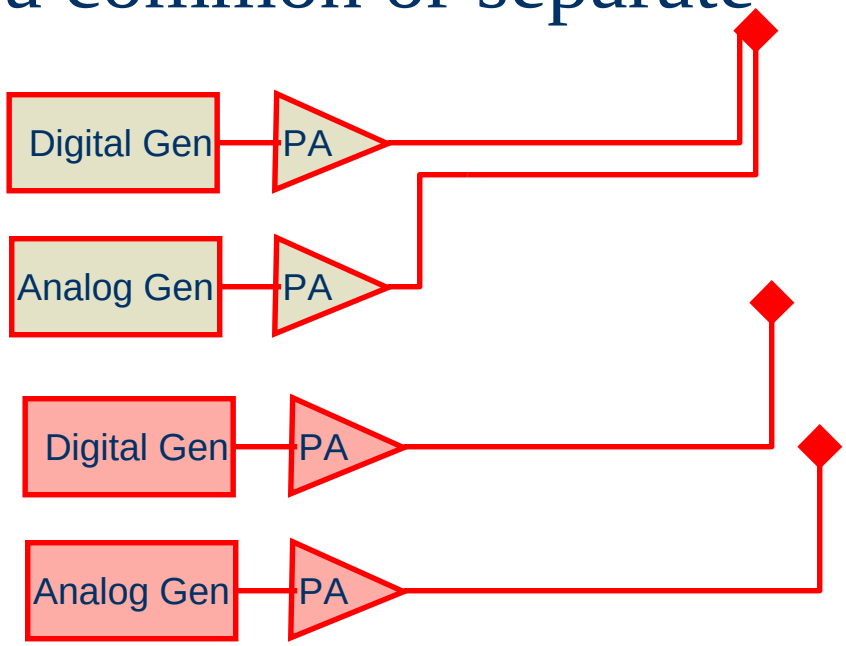
Common Line

- How to Measure
  - Establish analog reference
    - Note: Presence of IBOC causes only ~0.05 dB error
  - Measure digital in presence of analog



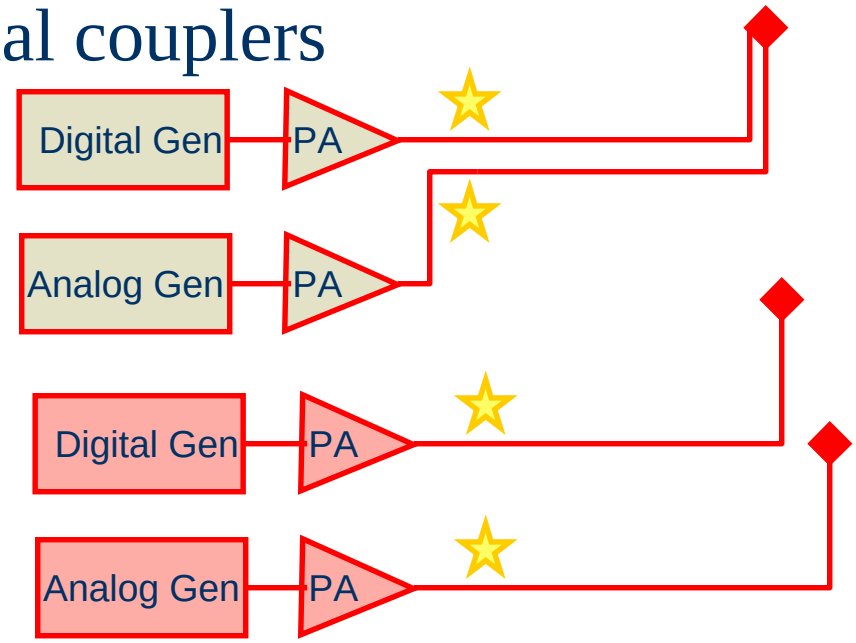
Separate Line

- Analog and Digital do not exist together in an accessible transmission line prior to being radiated from either a common or separate antenna
  - Dual input antennas
  - Separate antennas



Separate Line

- Sample points using directional couplers in transmission line
  - Calibrated directional couplers
  - Separate Lines

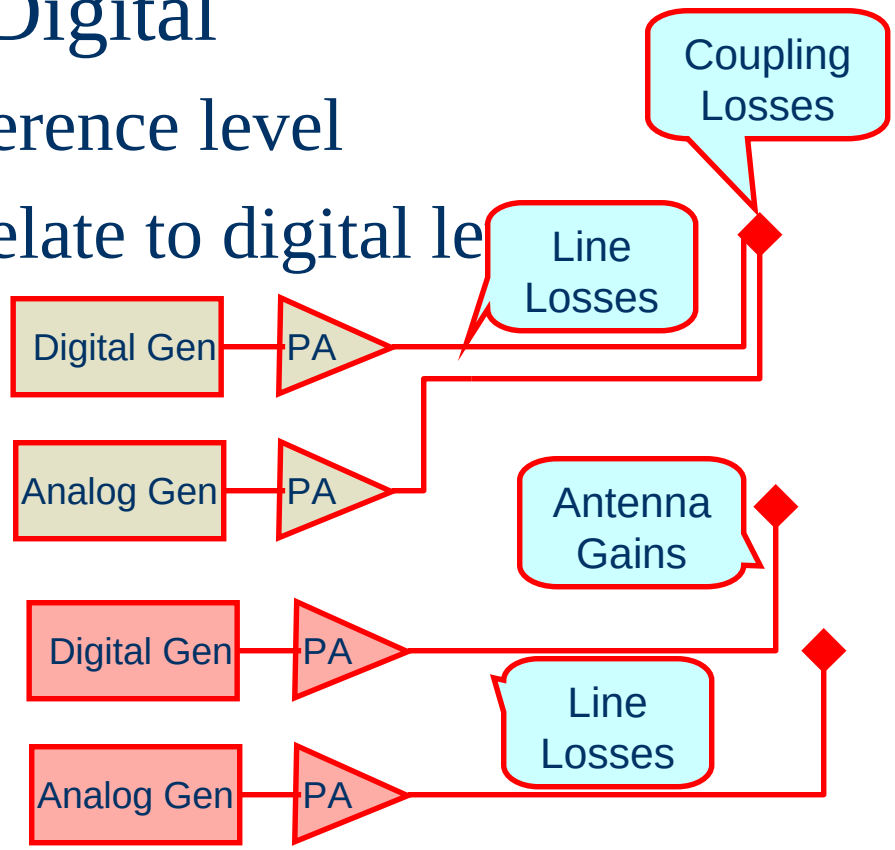


Separate Line

- Sample points using directional couplers in transmission lines
  - Calibrated directional couplers required
    - Must relate analog power to digital
    - Typical coupling level: -40 dB
    - Typical directivity: <-35 dB

Separate Lines

- Relating Analog to Digital
  - Establish analog reference level
  - Use loss budget to relate to digital le



Sample Loss Budget for TPO Calcs

Station Call Sign	**WXXX**	
Frequency (MHz)	**88.1**	
	Analog	**Digital**
ERP (W)	**50000**	**500**
Antenna Model	4-bay ERI Model 1082-4CP-DA	
Antenna Gain (multiplier)	4.67	4.67
Antenna input power (W)	**10707**	**107**
Main Horizontal and Vertical Line	3-1/8" Rigid Coax	1-5/8" Heliax HJ7-50A
Line Length (feet)	500	500
Line loss per hundred feet (dB/100')	-0.0872	-0.190
Line loss total (dB)	-0.4360	-0.9507
Analog to Digital Isolation base of feedlines (dB)	-22	
Analog to Digital Isolation at Antenna Input (dB)	-20.61	
Analog to Digital Coupling Loss (dB)	-0.0379	
Power Into Base of Vertical Line Run (W)	**11941**	**134**

Courtesy of ERI

Sample Loss Budget for TPO Calcs

Power Into Base of Vertical Line Run (W)	**11941**	**134**
Coupled Power at Filter Output Ports (W)	75	1
Filter Insertion Loss (dB)	-0.370	-0.450
Power Input to Filter (W)	**13003**	**149**
Circulator Insertion Loss (dB)	0	-0.45
Digital Power Input to Circulator	NA	**165**
TX to Circulator Line	NA	1/2" Foam LDF4-50A
Line Length (feet)	0	50
Line loss per hundred feet (dB/100')	0.000	-0.619
Line loss total (dB)	0.0000	-0.310
TPO (W)	**13003**	**178**

Courtesy of ERI

In Field

- Off-air sampling is most challenging
  - Localized multipath and fading can spoil accuracy of measurement
  - Adjacent signals may obscure regrowth
  - May be only way to see full hybrid signal

Summary

- Common Amplification
  - More points of spectral regrowth possible vs. Separate Amplification
- Common Line
  - Measure analog vs. digital directly
  - Separate lines require calibration
    - Directional couplers
    - Loss budget

Summary

- Analyzer setting
  - Must have good intermodulation specs
  - 100-dB on-screen range helpful
  - 1kHz RBW desirable
    - But in a pinch, 3 kHz works
  - Mind extraneous signals
  - Read The Manual!
    - Total power into analyzer must be safely below analyzer compression
    - Minimum measured signal must be above instrument noise floor

Summary

- Analyzer setting
  - Channel Power computation feature
    - Most desirable
  - Sample detection mode and multi-sweep averaging
    - Good (15 sweeps OK, 50 pretty)
  - Max-Min (a.k.a. Pos-Neg) trace averaging
    - Less precise
  - Very narrow Video Bandwidth
    - In the ballpark, but slow and less precise.

Protocol?

- A measurement protocol should be
  - Simple
  - Sufficient
  - Repeatable
  - Standard

Protocol?

- Simple
  - Reasonably affordable equipment
  - Straightforward procedure

Protocol?

- Sufficient
  - Identify the least that needs measuring to confirm compliance and compatibility for enforcement (pass/fail)
    - Masks should suffice
  - Identify more precise methods for evaluating qualitatively
    - Apply special case rules for certain adjacent channel issues, e.g. D/U ratios of adjacent stations versus co-channel spectral regrowth energy

Protocol?

- Repeatable
  - Licensees and regulators should test in same manner
  - Accept 2.5 dB adjustment for analog IF instruments
  - Use ENBW corrections only if results are borderline

Protocol?

- Standard
  - NRSC would be a good source for a consensus on interference criteria and measurement protocols.
  - If NRSC were to establish standards, FCC could validate and adopt.

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Presentation will be available for download
in the digital radio section at:

www.broadcastsignallab.com